CALIFORNIA
ENERGY
COMMISSION

ENERGY INNOVATIONS SMALL GRANT PROGRAM
Building End Use Technologies

Energy Shaver - A Thermal Energy Storage Device for Air Conditioners

FEASIBILITY ANALYSIS

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PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million of which $2 million/year is allocated to the Energy Innovation Small Grant (EISG) Program for grants. The EISG Program is administered by the San Diego State University Foundation under contract to the California State University, which is under contract to the Commission.

The EISG Program conducts four solicitations a year and awards grants up to $75,000 for promising proof-of-concept energy research.

PIER funding efforts are focused on the following six RD&D program areas:

- Residential and Commercial Building End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

The EISG Program Administrator is required by contract to generate and deliver to the Commission a Feasibility Analysis Report (FAR) on all completed grant projects. The purpose of the FAR is to provide a concise summary and independent assessment of the grant project using the Stages and Gates methodology in order to provide the Commission and the general public with information that would assist in making follow-on funding decisions (as presented in the Independent Assessment section).

The FAR is organized into the following sections:

- Executive Summary
- Stages and Gates Methodology
- Independent Assessment
- Appendices
  - Appendix A: Final Report (under separate cover)
  - Appendix B: Awardee Rebuttal to Independent Assessment (Awardee option)

For more information on the EISG Program or to download a copy of the FAR, please visit the EISG program page on the Commission's Web site at:
http://www.energy.ca.gov/research/innovations

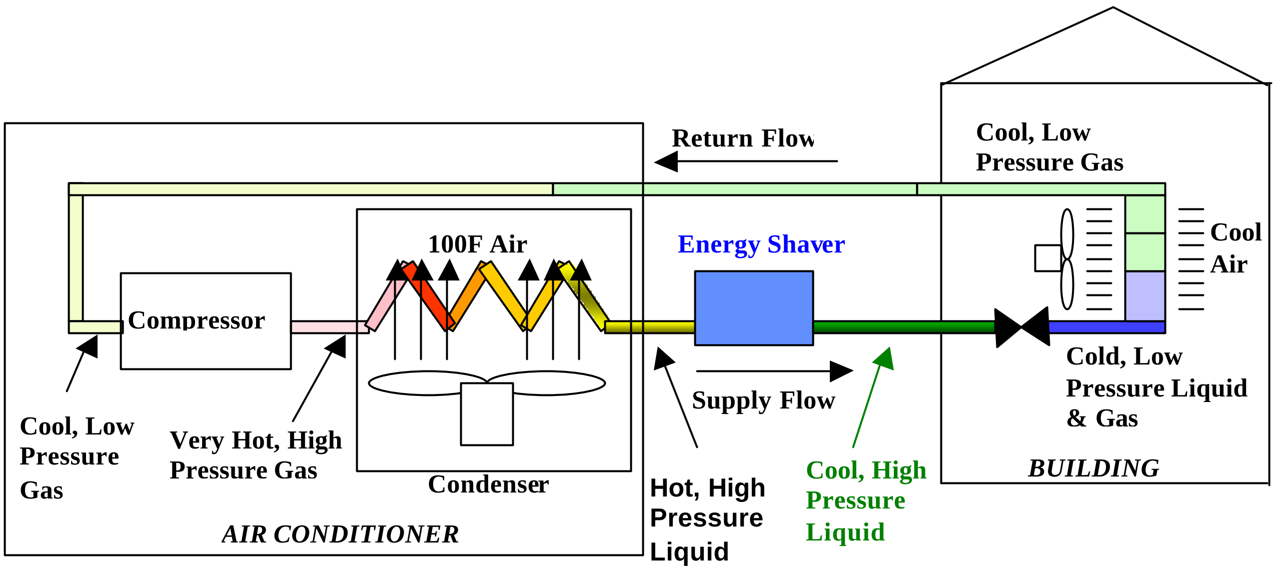
or contact the EISG Program Administrator at (619) 594-1049 or email eisgp@energy.state.ca.us.

For more information on the overall PIER Program, please visit the Commission's Web site at http://www.energy.ca.gov/research/index.html.

Executive Summary

Introduction

This project researched the feasibility of using a thermal energy storage device based on a salt hydrate to improve the performance of vapor-compression air conditioners of less than 5 tons capacity. A device using a salt hydrate to provide a relatively cool heat sink for the air conditioner working fluid during the hot part of the day was investigated. The stored heat is rejected from the salt hydrate to cooler night air to complete the cycle. With this device, an air conditioner can be up to 30% more efficient on very hot days. The schematic shown illustrates



this system. Thermal energy storage systems that use salt hydrates have been used for many years in solar heating systems. The innovation in this project is the use of salt hydrates for energy storage on the hot side of a vapor compression air conditioner.

Objectives

The goal of this project was to prove the feasibility of using a salt hydrate energy storage device to improve the efficiency of existing vapor-compression air conditioners. The researcher established the following objectives:

1. Perform preliminary modeling of the air-conditioner/energy storage system
2. Model the salt hydrate containers
3. Select the energy storage system materials
4. Model and bench test the heat exchanger and related components
5. Perform final modeling of the energy storage system.

Outcomes

1. The researcher wrote a FORTRAN computer program to model air-conditioning systems of 5 tons or less. This model used the FORTRAN-compatible Gaspak^{tm} fluid properties program package to calculate refrigerant properties. A reciprocating compressor for the model was chosen. Future researchers must modify the model to incorporate the more common scroll compressors. The project exercised the model for numerous sets of conditions.
2. This project found that an acceptable salt hydrate container is one that meets the heat transfer requirements with a pressure loss and airflow that can be obtained from a low cost fan. The surface area required for heat transfer for a 5-ton unit is 6306 in^2. The project analyzed several container wall geometries for the heat exchange surfaces. The baseline configuration is a cylindrical annulus 48 inches high, 17.5 / 20.5 inches inside/outside diameter, and having pleated surfaces.
3. The researcher, through review of literature, identified several useful hydrates: calcium chloride hexahydrate, sodium sulfate decahydrate, disodium phosphate dodecahydrate, and mixtures of sulfate and phosphate hydrates. These hydrates are compounds of salts and water in which the water bonds to the salt molecules when the temperature drops below the freezing point of the hydrate. This gives the hydrate a large latent heat of fusion that is released when the water/salt solution freezes. The selected mixture was 5/35/60% phosphate/sulfate/ water with 3% borax additive.
4. The researcher substituted water for Freon^{tm} in the system bench test. Tube spacing, container wall spacing and the hydrate were the same as in the planned, full-size energy storage device. For the heat flux per degree of temperature difference to be the same for the full-size energy storage device and the bench-test energy storage device, a scaling factor was calculated. Using this scaling factor the researcher built a bench-test heat exchanger tube six feet long to maintain equivalent heat transfer.
5. The project iteratively updated the model of the energy storage device and incrementally improved it during the project bench test. The researcher incorporated the results of the tests as well as the empirically determined heat transfer coefficient in the model.

Conclusions

The project results indicate the technology is feasible and the salt hydrate energy storage device could provide measurable benefit when installed in an existing system. On a new or replacement system, the user would see immediate cost savings from reduced demand charges and energy consumption. The researcher suggests new replacement air conditioners equipped with the salt hydrate energy storage device could be smaller; therefore, they could cost the same as or less than the larger units they replace. This would offer an immediate payback.

1. The system modeling produced the following conclusions:

- Project results indicate a demand reduction of 25% and an energy savings of 23% are possible when a 3-ton air conditioner augmented with the energy storage device replaces a 4-ton air conditioner. (The researcher made an unwritten assumption that comfort levels would be equivalent.) Energy savings are negligible for a simple retrofit into an existing air conditioning unit.

- Retrofit applications require modifications to the air conditioner evaporator to realize maximum benefits
- The energy storage device is best suited to applications where dehumidification is usually required.
- The melt/freeze cycle operates with normal ambient conditions.

2. Data from the salt hydrate modeling and testing led to the following conclusions:

- A nucleating agent is required to stabilize the refreeze temperature
- Some salt settling occurs with the selected mixture, resulting in a loss of thermal capacity of about 5%. Mixing or some other measure is needed to maintain long-term thermal performance. Additional energy is required for the mixing operation.

3. The researcher identified and used effective combinations of known salts for the energy storage device.

4. Bench tests led to the following conclusions:

- The scaled version of the Freon^{tm}-to-salt heat exchanger design did not perform as well as expected. The outlet temperature rose 22°F by the end of the test when the model predicted a rise of 18°F.
- Although the performance is adequate, additional heat transfer area (longer tubes or extended surfaces) is necessary to meet the stated heat transfer requirements.

5. The project produced data that has been incorporated into a model of the system. Future researchers in this field can use these data and the updated model.

Benefits to California

Electric power demand exceeds supply during hot summer days in many areas of the state. A large percentage of peak power demand is driven by air conditioning demand. Expanding new house construction in hot areas of the state is magnifying the problem. Almost all of these houses are equipped with air conditioning.

The salt hydrate energy storage device tested in this project would have a measurable impact on the California's energy consumption if it were widely implemented in new and replacement applications. Negligible benefits were found for simple retrofit. A significant portion of California has weather suitable for using this thermal storage device.

Recommendations

Two major areas requiring further development are mixing of the salt hydrate to ensure repeatable, long-term performance and product packaging to integrate the salt hydrate energy storage device with new or existing air conditioning equipment. Salt based energy storage systems, while offering great advantages to energy storage, have problems of heat transfer, settling, corrosion, and often cost. The PA recommends research work on these problems. Once solutions are found, the researcher should team with a manufacturer of air conditioning equipment to test a prototype energy storage system for energy performance and user comfort.

Stages and Gates Methodology

The California Energy Commission utilizes a stages and gates methodology for assessing a project's level of development and for making project management decisions. For research and development projects to be successful they need to address several key activities in a coordinated fashion as they progress through the various stages of development. The activities of the stages and gates process are typically tailored to fit a specific industry and in the case of PIER the activities were tailored to be appropriate for a publicly funded energy research and development program. In total there are seven types of activities that are tracked across eight stages of development as represented in the matrix below.

Development Stage/Activity Matrix

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Activity 1								
Activity 2								
Activity 3								
Activity 4								
Activity 5								
Activity 6								
Activity 7								

A description the PIER Stages and Gates approach may be found under "Active Award Document Resources" at: http://www.energy.ca.gov/research/innovations and are summarized here.

As the matrix implies, as a project progresses through the stages of development, the work activities associated with each stage needs to be advanced in a coordinated fashion. The EISG program primarily targets projects that seek to complete Stage 3 activities with the highest priority given to establishing technical feasibility. Shaded cells in the matrix above require no activity, assuming prior stage activity has been completed. The development stages and development activities are identified below.

Development Stages:	Development Activities:
Stage 1: Idea Generation & Work Statement Development Stage 2: Technical and Market Analysis Stage 3: Research & Bench Scale Testing Stage 4: Technology Development and Field Experiments Stage 5: Product Development and Field Testing Stage 6: Demonstration and Full-Scale Testing Stage 7: Market Transformation Stage 8: Commercialization	Activity 1: Marketing / Connection to Market Activity 2: Engineering / Technical Activity 3: Legal / Contractual Activity 4: Environmental, Safety, and Other Risk Assessments / Quality Plans Activity 5: Strategic Planning / PIER Fit - Critical Path Analysis Activity 6: Production Readiness / Commercialization Activity 7: Public Benefits / Cost

Independent Assessment

For the research under evaluation, the Program Administrator assessed the level of development for each activity tracked by the Stages and Gates methodology. This assessment is summarized in the Development Assessment Matrix below. Shaded bars are used to represent the assessed level of development for each activity as related to the development stages. Our assessment is based entirely on the information provided in the course of this project, and the final report. Hence it is only accurate to the extent that all current and past work related to the development activities are reported.

Development Assessment Matrix

Stages / Activity	1 Idea Generation	2 Technical & Market Analysis	3 Research	4 Technology Development	5 Product Development	6 Demonstration	7 Market Transformation	8 Commercialization
Marketing								
Engineering / Technical								
Legal/ Contractual								
Risk Assess/ Quality Plans								
Strategic								
Production. Readiness/								
Public Benefits/ Cost								

The Program Administrator's based his assessment on the following supporting details:

Marketing/Connection to the Market. -- The target market identified was the residential and small commercial end user with units less than 5-ton capacity. San Diego Gas & Electric has expressed interest in the Energy Shaver (salt hydrate energy storage system name) and has funded continued testing of the concept.

Engineering/Technical. -- Product performance goals were not included in the final report. The researcher qualitatively demonstrated the technical feasibility of using a phase-change material to provide a cool heat sink for the working fluid in air conditioners. There was insufficient backup of quantitative values.

Legal/Contractual. The researcher has filed a patent disclosure, but he has not disclosed other legal issues/resolution.

Environmental, Safety, Risk Assessments/ Quality Plans. -- Documented Quality Plans, where appropriate, are required prior to initiation of Stage 4 development activity. The researcher must provide plans in the following areas: Reliability Analysis, Failure Mode Analysis, Manufacturability, Cost and Maintainability Analyses, Hazard Analysis, Coordinated Test Plan, Product Safety and Environmental.

Strategic. This product has no known critical dependencies on other projects under development by PIER or elsewhere

Production Readiness/Commercialization There is no indication that this project has identified potential commercializing partners. For the California ratepayers to benefit from the Energy Shaver, the researcher must transfer the technology to a manufacturer of air conditioning equipment.

Public Benefits. PIER research public benefits are defined as follows:

- Reduced environmental impacts of the California electricity supply or transmission or distribution system.
- Increased public safety of the California electricity system
- Increased reliability of the California electricity system
- Increased affordability of electricity in California

The primary public benefit offered by the proposed technology is to make electricity more affordable in California. If the Energy Shaver were to be widely employed, the demand for electricity to power small air-conditioners would be greatly reduced. Reduced demand should result in greater availability and therefore lower costs.

Appendix A: Final Report, including an addendum of product development subsequent to the research project (under separate cover.)

Appendix B: Awardee Rebuttal to Independent Assessment (none submitted.)